NAVAL BIODYNAMICS LABORATORY
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# X-RAY ANTHROPOMETRY TRANSFORMATION PROGRAM FOR THE HEWLETT-PACKARD 9000/835 COMPUTER

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Software Documentation

May 1991

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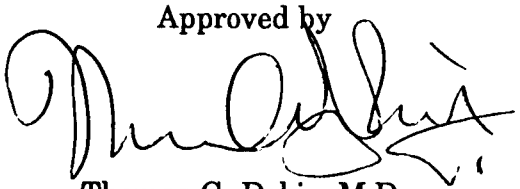

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Chairman, Scientific Review Committee

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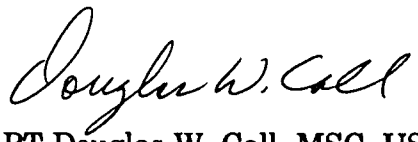

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# X-RAY ANTHROPOMETRY TRANSFORMATION PROGRAM

# FOR THE HEWLETT-PACKARD 9000/550 COMPUTER

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## 1. INTRODUCTION

The Naval Biodynamics Laboratory (NAVBIODYNLAB), located in New Orleans, Louisiana, is a research facility under the cognizance of the Naval Medical Research and Development Command. It is the only Navy laboratory conducting biomedical research on the effects of mechanical forces (motion and impact) encountered by Navy personnel. Among its goals are the establishment of human tolerance limits and the development of appropriate methods of avoiding and treating the deleterious effects of such forces. Ongoing research programs at the laboratory acquire sensor and photographic impact acceleration data from acceleration sled runs.

To analyze this data, certain anthropometric information about each subject is necessary: the locations of the head and the first thoracic vertebral body (T-1) instrumentation origins relative to the corresponding anatomical origins, as well as transformation matrices from the instrument to the anatomical coordinate systems.

A stereoradiographic technique, in which two simultaneous X-ray exposures of an instrumented subject are prepared and analyzed, is used to measure the geometrical relationships between subject mounted-instrumentation and subject anatomy. This yields a complete six-parameter statement of the position and orientation of the instrument package relative to a coordinate system fixed in the subject's bony anatomy. In the anatomical coordinate system, the mounted instrumentation is assumed to be rigidly fixed. If the geometrical relationship of these systems is known, then the transformation from one system to the other is a matter of rigid body mechanics.

Stereoradiographic techniques have been devised at the Naval Biodynamics Laboratory to measure the geometrical relationships between subject-mounted instrumentation and subject anatomy. Measurements for instrumentation mounts are made at the head and T-1.

Packages consisting of photographic targets and accelerometers that are fixed to a rigid T-shaped plate are attached to human and human analog subjects by means of an intermediary anatomical mount. These mounts are prepared so that one surface provides a rigid and highly repeatable mooring for the instrumentation packages, while another is custom molded to fit the subject's dental surfaces or bony protuberances of the spine or pelvis. The transformation from anatomical to instrumentation coordinates is governed by these anatomical mounts, with a single transformation uniquely associated with each.

Quantization of these transformations is performed radiographically. The subject is X-rayed while wearing lead markers on externally accessible anatomical features. Also worn are anatomical mounts equipped with special Plexiglass™ T-plates, in which additional lead markers ("BBs") have been fixed at known locations. The X-ray images of these markers and of other anatomical features establish the laboratory reference position of the test subject and the orientation of the instrumentation and anatomical coordinate systems. This information is used to convert anatomical to instrumentation data.

Two groups of anatomical coordinates are presently used in the work conducted at NAVBIODYNLAB. One is located in the bony anatomy of the head, the other in the first thoracic vertebral body (T-1). The head coordinate system is defined by the positions of the two auditory meatus and the notches on the inferior orbital ridges. Its origin is the midpoint of the line joining the auditory meatus. The X axis is positive from the origin through the midpoint of the line connecting the orbital notches. The X-Y plane contains the X axis and the midpoints of the lines from the left orbital notch to the left auditory meatus and from the right orbital notch to the right auditory meatus. The Z axis is positive through the top of the skull. The T-1 coordinate system is also based on four points: the posterior tip of the posterior spinous process, the anterior-superior corner of the vertebral body, and the superior corners of the right and left articular facets. Unfortunately, most of these points are not directly accessible for marking and are visible only in certain X-ray projections.

Therefore, the suprasternal notch, an externally accessible site, is used to locate a system with the anterior-superior corner at T-1, with the X axis going through the posterior tip of the posterior spinous process and positive anteriorly, and with the Y axis parallel to the line connecting the two articular facets and positive left. The Z axis is positive up.

Since the radiologic equipment used at NAVBIODYNLAB is primarily intended for diagnostic use rather than for stereometric measurement, there is no direct means of obtaining a precise statement of the system geometry necessary for this application. Therefore, stereoradiographs of a special calibration device are prepared. This device consists of thirteen lead markers set at known positions in a radiolucent Plexiglas™ prism. The prism is placed so that at least eight of the markers will be visible in each of the two X-ray exposures. The body coordinates of this prism as it is radiographed become the arbitrary laboratory reference frame. Two X-rays are taken, an anterior-posterior and a lateral projection. Markers placed on the auditory meatus and the notches of the inferior orbital ridges, as well as those in the Plexiglas™ T-plate, are clearly visible in them. The positions of these images in each of the projections can then be made to yield their lab-oriented positions, which will in turn yield the orientations and lab-oriented positions of the anatomical and instrumentation coordinates, and finally the transformation from one to the other.

The anterior-posterior and lateral X-rays are also used to quantize the T-1 instrumentation coordinate data. Markers placed on the suprasternal notch and over the T-1 posterior spinous process, as well as those in the plexiglass T-plate, are clearly visible in each X-ray. In addition, the superior corners of the right and left articular facets are visible in the anterior-posterior X-rays, and the anterior-superior corner and the superior and inferior corners of the posterior spinous process are visible in the lateral ones.

After X-rays have been taken and developed, they are examined to determine that all the various markers and anatomical features are visible. The person overseeing radiological operations locates and marks the various anatomical landmarks for digitization. In digitization, the position of each marker and landmark is measured and compared to the orientation information. Digitized positions are subjected to computational procedures to determine, first, the geometrical layout of the radiologic equipment, and then the geometry relating the mounts to the anatomy. The computation is essentially a least squares iteration.

## 2. FUNCTION

The following program and subroutines are used:

| | |
|---|---|
| MXRAY: | Main program, which allows operator to select major options. |
| AXEB: | Inverts a matrix. |
| CDNTPT: | Calculates and prints transformation matrices. |
| POBKG: | Calculates the likeliest position and orientation of a rigid body of known geometry. |
| PXRY2: | Calculates the least-squared coordinates. |
| RLSWCH: | Right-left switch. |
| OPTION: | Compares calculations and uses switched values if indicated. |
| PRISM2: | Reads and reduces calibration data. |
| HTRANS: | Calculates the position and orientation of the head coordinates. |

## 3. MAIN PROGRAM

### 3.1 MXRAY

This interactive program calculates X-ray anthropometry transformation matrices. The output consists of a printout and a data file containing the "Instrumentation vs. Anatomy" matrix, which is the input to the Anthropometry Data Base Update program. The following input is requested:

Subject Number (A6 format)
Date of X-ray (MON YR A6 format)
Julian Date of X-ray (I5 format)
Pcode (*a* for A-plate or *t* for T-plate, A1 format)
Julian Date of X-ray (day, year; I3,I2 format)
Option code "jo" and processing code "kk" (2I1 format)
- jo = 1 exercise the option (standard operation — always 1)
- jo = (any other number) option not exercised
- kk = 1 process head and neck data
- kk = 2 process head data only
- kk = 3 process neck data only
- kk = 4 process pelvic data only
- kk = 7 redo program
- kk = 9 end program

Comments for head data

Comments for neck data
Block or No block for neck data

## 3.2 COMPILATION

All of the subroutines needed to execute MXRAY are stored in the file 'libxrayantm.a,' which is in the users' library ('/usr/lib/'). The program was compiled with the following command:

**fc mxray.f /usr/libxrayantm.a -o mxray**

## 3.3 DATA FILES

The file 'input' should always contain the subject data to be processed. The file 'output' will always be used to store the processed data. The file 'update' will always be used to store the transformation matrices. The file 'IOupdate' is a shell procedure that updates the input file, saves the previous output, and executes the main program.

## 3.4 EXECUTION

The executable code is stored in the file 'mxray.' To execute the program, execute the shell procedure 'IOupdate' by typing the appropriate file names in the following form:

***IOupdate newinputfilename oldoutputfilename oldupdatefilename***

Assuming subject H00290 was processed, the output from program execution is in files 'output' and 'update.' The data will be saved on the next execution of 'IOupdate.' The user input would be as follows:

***IOupdate input H00290.out H00290.up***

The file 'input' contains data for the subject to be processed. The naming convention for the files 'oldoutputfilename' and 'oldupdatefilename' is 'subjectID.out' and 'subjectID.up,' respectively.

The program will request input, organize and coordinate calculations. To get printed results, execute the "lp" command using the file 'output.'

# 4. SUBROUTINE DESCRIPTIONS

## 4.1 AXEB

The routine AXEB inverts a matrix. The call is:

***call axeb (a,n,n1,jc)***

where

A = the matrix to be inverted
N = the number of rows in matrix A
N1 = the number of columns in matrix A
JC = the work array used by this routine

## 4.2 CDNTPT

The routine CDNTPT calculates in anatomical coordinates the vector from the instrument origin to the anatomical origin. It also generates the transformation matrix that translates a vector from the instrumentation coordinate system to the anatomical coordinate system. The call is:

***call cdntpt***

## 4.3 POBKG

The routine POBKG calculates the vector defining the instrument origin lab coordinates and also calculates the transformation matrix from the instrument to the laboratory system. The call is:

***call pobkg (x,xx,ii,pp,a)***

where

X = represents a two-dimensional, three-by-three array containing the best least squares coordinates of the center right, and left T-plate BBs in the lab coordinate system as calculated in subroutine PXRY2
XX = a two-dimensional, three-by-three array containing the location of the three instrument BBs in the instrument coordinate system
II = the number of BBs on the T-plate (normally 3)
PP = the vector defining the instrument origin in lab coordinates

A = the transformation matrix (3 × 3) that takes a vector from the instrument coordinate system and translates it into the lab coordinate system

## 4.4 PXRY2

The routine PXRY2 calculates the best least square coordinates in the lab coordinate system. The call is:

***call pxry2 (x,a,r,xr)***

where

X = the best least squares estimate of BBs in lab coordinates
A = the measured X-ray coordinates of the nth BB
R = the sum of the square of the error between the measured and the projected X-ray coordinates
XR = the X-ray coordinates obtained by projection of the calculated position of the BB onto the X-ray film planes

## 4.5 RLSWCH

The routine RLSWCH allows an optional right-left switch of the anterior-posterior (AP) and lateral X-ray coordinates. The call is:

***call rlswch (j,k,sp)***

where

J = represents the index of the right side BB on the lateral view as obtained from measurement
K = the index of the right side BB so labeled by this subroutine and has identical X-ray coordinates as the measured labeled left side BB
SP = the array containing the measured coordinates of the AP and lateral views. This array also contains the right-left/left right switch of coordinates in the last 24 elements

## 4.6 OPTION

The routine OPTION compares the error associated with the measured location of right and left BBs with the error associated with the right and left BBs as defined in subroutine RLSWCH. If the error is smaller for the point as labeled, the routine prints "Option Not Indicated." If the error is greater, the routine may either disregard the as-labelled calculation and use that of the switched labels (defined by subroutine RLSWCH) and print "Option Indicated and Exercised"; or, if the operator wishes, continue to use the as-labeled calculation and print "Option Indicated But Ignored." The call is:

***call option (j,k,er,x,jo)***

where

J = the number of the right-side BBs as obtained from lateral view measurements

K = the number of the right-side BBs as labeled by subroutine RLSWCH

ER = a one-dimensional array containing the sum of the squares of the difference between the "measured" and "calculated" AP and lateral X-ray coordinates of the BB under scrunity

X = two-dimensional, three-by-thirteen array containing the best least squares coordinates for the BB under scrutiny, as calculated in subroutine PXRY2

JO = the code that determines if an option is to be exercised, as follows:

| | |
|---|---|
| 1 | — Exercise option |
| Any other number | — Do no exercise option |

## 4.7 PRISM2

The routine PRISM2 reads and reduces calibration data. This subroutine establishes the lab coordinate system and calculates both the AP and lateral camera orientations and positions. The call is:

***call prism2 (xop,xsp,cp)***

where

XOP = the best estimate of the vector from lab to X-ray origin in X-ray coordinates

XSP = the best estimate of the vector from source origin to X-ray origin in X-ray coordinates

CP = the best estimate of the transformation matrix from lab to X-ray

### 4.8 HTRANS

The routine HTRANS calculates the anatomical origin of the head in lab coordinates and the transformation matrix, which takes a vector in lab coordinates and transforms it into a vector in the head anatomical coordinate system. The call is:

***call htrans (x)***

where

X = the array containing the lab coordinates of the four head anatomical BBs plus the three T-plate BBs plus the six coordinates obtained by performing a right-left/left-right switch of measure-defined locations of BBs from the X-ray view

## 5. UTILITY SUBROUTINES

Two utility subroutines are used in the X-ray transformation program and are included for completeness. A brief description of each is given in this section.

### 5.1 CAPS

The routine CAPS enables the 'caps' mode on the HP-2627A terminal. The call is:

***call caps***

### 5.2 CAPOFF

The routine CAPOFF disables the 'caps' mode on the HP-2627A terminal. The call is:

***call capoff***

## REFERENCE

Becker, E. B., "Stereoradiographic Measurements for Anatomically Mounted Instruments," *Proceedings of the Twenty-First STAPP Car Crash Conference*, Society of Automotive Engineers, Inc., Warrendale, PA, pp. 477–505, October 1977.

# APPENDIX A

## Program Listings

```
FORTRAN 77/UX  HP92430A.07.04  COPYRIGHT HEWLETT-PACKARD CO. 1983.
Thu Jul 26 14:20:18 1990


 1          subroutine axeb (a,n,n1,jc)
 2    c
 3    c  This routine inverts a matrix
 4    c
 5    c  a  -  matrix to be inverted
 6    c  n  -  number of rows in matrix a
 7    c  n1 -  number of columns in matrix a
 8    c  jc -  work array used by this routine
 9    c
10          real a(n,n1)
11          integer jc(n)
12    c
13    c  assign a unit number to the output file
14          open(11,file='output')
15    c
16          do 70 i=1,n
17          x=-1.
18          m=i
19          do 10 j=m,n
20          if (abs(a(j,i)).lt.x) go to 10
21          x=abs(a(j,i))
22          l=j
23    10 continue
24          c
25          c  check matrix for singularity
26          c
27          jc(i)=l14
28          if (x) 20,90,20
29    20  do 30 j=1,n1
30          x=a(i,j)
31          a(i,j)=a(l,j)
32    30  a(l,j)=x
33          x=a(i,i)
34          a(i,i)=1.
35          do 40 j=1,n1
36    40  a(i,j)=a(i,j)/x
37          do 60 j=1,n
38          if (j.eq.i) go to 60
39          x=a(j,i)
40          a(j,i)=0.
41          do 50 k=1,n1
42    50  a(j,k)=a(j,k)-x*a(i,k)
43    60  continue
44    70  continue
45          do 80 i3=1,n
46          i=1+n-i3
47          l=jc(i)
48          do 80 j=1,n
49          x=a(j,i)
50          a(j,i)=a(j,l)
51    80  a(j,l)=x
52          return
53    90 write (11,100)
54          jc(1)=-1
55          return
56    c
57          100 format ('  disaster - ill conditioned matrix')
```

```
58   c
59         end

NUMBER OF ERRORS =   0  NUMBER OF WARNINGS =   0
```

```
FORTRAN 77/UX  HP92430A.07.04  COPYRIGHT HEWLETT-PACKARD CO. 1983.
Thu Jul 26 14:20:19 1990


 1          subroutine capoff
 2    c
 3    c  FUNCTION:
 4    c  Disables the 'caps' mode on the HP-2627A terminal.
 5    c
 6    c  BY:
 7    c  D. Francis
 8    c  Naval Biodynamics Laboratory
 9    c  New Orleans, Louisiana
10    c  28 June 1988
11    c
12          equivalence (ESCA,IEA),(AK0,IK0),(PP,IPP)
13    c
14          character*2 ESCA,AK0,PP
15    c
16          data IESCA/o'015446'/,K0/o'065460'/,IPSP/o'050040'/
17    c
18          call mvbits(IESCA,0,16,IEA,16)
19          call mvbits(K0,0,16,IK0,16)
20          call mvbits(IPSP,0,16,IPP,16)
21    c
22          write(6,10) ESCA,AK0,PP
23    10   format(6a2)
24    c
25          return
26          end

NUMBER OF ERRORS =   0  NUMBER OF WARNINGS =   0
```

```
FORTRAN 77/UX  HP92430A.07.04  COPYRIGHT HEWLETT-PACKARD CO. 1983.
Thu Jul 26 14:20:19 1990

 1          subroutine caps
 2   c
 3   c  FUNCTION:
 4   c  Enables the 'caps' mode on the HP-2627A terminal.
 5   c
 6   c  BY:
 7   c  D. Francis
 8   c  Naval Biodynamics Laboratory
 9   c  New Orleans, Louisiana
10   c  28 June 1988
11   c
12          equivalence (ESCA,IEA),(AK1,IK1),(PP,IPP)
13   c
14          character*2 ESCA,AK1,PP
15   c
16          data IESCA/o'015446'/,K1/o'065461'/,IPSP/o'050040'/
17   c
18          call mvbits(IESCA,0,16,IEA,16)
19          call mvbits(K1,0,16,IK1,16)
20          call mvbits(IPSP,0,16,IPP,16)
21   c
22          write(6,10) ESCA,AK1,PP
23   10   format(6a2)
24   c
25          end

NUMBER OF ERRORS =  0  NUMBER OF WARNINGS =  0
```

```
FORTRAN 77/UX  HP92430A.07.04  COPYRIGHT HEWLETT-PACKARD CO. 1983.
Thu Jul 26 14:20:24 1990


 1          subroutine cdntpt
 2    c
 3    c  This subroutine calculates in anatomical coordinates the vector from
 4    c  instrument origin to the anatomical origin.  It also generates the
 5    c  transformation matrix that take a vector from the instrumentation
 6    c  coordinate system to the anatomical coordinate system.
 7    c
 8    c  input consist of common/blk1/arrays;
 9    c
10    c  xh(3)  = created in subroutine htrans and is the vector defining the
11    c  anatomical origin in lab coordinates.
12    c
13    c  ah(3,3) = created in the subroutine htrans and is the transformation
14    c  matrix that takes a vector from the lab into the anatomical
15    c  coordinate system.
16    c
17
18    c  xt(3)  = created in subroutine pobkg where it was called 'pp(i)';
19    c  vector defining the instrument origin in lab coordinates
20    c
21    c  at(3,3) = created in subroutine pobkg where it was called 'a(3,3)';
22    c  transformation matrix that takes a vector from instruments
23    c  into the lab coordinate system.
24    c
25    c  Output consists of arrays
26    c
27    c  r(i)  = r(i) + ah(i,j) * xh(k,j)
28    c  The instrument origin vector transformed into the head
29    c  anatomical coordinate system where
30    c  xh(k,j) = xt(i)-xh(i) the vector from the
31    c  instrument origin to the anatomy origin in lab coordinates.
32    c
33    c  aa(i,j) = aa(i,j) + ah(i,k)*at(k,j)
34    c  where aa(i,j) = the transformation matrix that takes a
35    c  vector in instrument coordinates and expresses it in
36    c  anatomy coordinates.
37    c
38    c
39          real aa(3,3), r(3)
40          integer sday,syear,eday,eyear
41          character*6 nsub,dat,blk
42          character*6 not(9)
43    c
44          common /blk1/ xh(3),ah(3,3),xt(3),at(3,3)
45          common /c1/ nsub,nmnt,dat,blk,not,sday,syear,eday,eyear
46    c
47    c  assign a unit number to the output file
48          open(11,file='output')
49          open(12,file='update')
50    c
51          write (11,100)
52          do 10 i=1,3
53          write (11,50) xh(i),(ah(i,j),j=1,3),xt(i),(at(i,j),j=1,3)
54    10   xh(i)=xt(i)-xh(i)
55          write (11,90)
56          do 30 i=1,3
57          r(i)=0.
58          do 20 j=1,3
```

```
59          aa(i,j)=0.
60          r(i)=r(i)+ah(i,j)*xh(j)
61          do 20 k=1,3
62    20  aa(i,j)=aa(i,j)+ah(i,k)*at(k,j)
63    30  write (11,60) r(i),(aa(i,j),j=1,3)
64          c
65          c  write output data to update file
66          c
67          write(12,110) nsub,nmnt,dat,blk,(not(j),j=1,5),sday,s year,eday,
68         *eyear
69          write(12,80) (r(i),i=1,3)
70          do 40 i=1,3
71          write(12,70) (aa(j,i),j=1,3)
72    40  continue
73          c
74          return
75    c
76    50 format (2(5x,f10.4,3x,3f10.8))
77    60 format (5x,f10.4,3x,3f10.8)
78    70 format (3(f10.8,2x))
79    80 format (3(f10.6,2x))
80    90 format (///12x,'instrumentation vs anatomy'/)
81    100 format (///18x,'anatomy vs lab',27x,'instrumentation vs lab'/)
82    110 format (a6,2x,i4,2x,2(a6,3x),5a6,4x,2(i3,i4))
83    c
84          end

NUMBER OF ERRORS =  0  NUMBER OF WARNINGS =  0
```

```
FORTRAN 77/UX  HP92430A.07.04  COPYRIGHT HEWLETT-PACKARD CO. 1983.
Thu Jul 26 14:20:25 1990

 1          subroutine htrans (x)
 2    c
 3    c  subroutine htrans
 4    c
 5    c
 6    c  This subroutine calculates the anatomical origin of the head
 7    c  in lab coordinates and the transformation matrix which takes
 8    c  a vector in lab coordinates and transforms it into a vector
 9    c  in the head anatomical coordinate system.
10    c
11    c  input consist of:
12    c  x(3,13) = the lab coordinates of the 4 head anatomical bee bee's
13    c  plus t3 t-plate bee bee's plus the 6 coordinates obtained
14    c  by performing a right-left/left-right switch of measure
15    c  defined locations of bee's bee's from the x-ray view.
16    c  These are computed in subroutine pxryz by a least squares
17    c  technique.
18    c
19    c  xt(3t(3)  = created in subroutine pobkg where it was called 'pp(i)'
20    c  and  and is the vector defining the instrument origin i
21    c  lab coordinates.
22    c
23    c  at(3,3) = created in subroutine 'pobkg' where it was called 'a(3,3)'
24    c  and is the transformation matrix that takes a vector from
25    c  instrument trument into the lab coordinates system.
26    c
27    c  output consist of:
28    c  xh(i)  = (x(i,2) + x(i,1))/2 = anat origin in lab.
29    c
30    c  ah(3,3) = is the transformation matrix which takes a vector in lab
31    c  coordinates and transforms it into a vector in the head
32    c  anatomical system.
33    c
34          common /blk1/ xh(3),ah(3,3),xt(3),at(3,3)
35          real x(3,13)
36          do 10 i=1,3
37          xh(i)=(x(i,2)+x(i,1))/2.
38          ah(1,i)=x(i,3)+x(i,4)-x(i,1)-x(i,2)
39          ah(2,i)=x(i,2)+x(i,4)-x(i,1)-x(i,3)
40          10  ah(3,i)=0.
41          do 20 i=1,3
42          ah(3,1)=ah(3,1)+ah(1,i)**2
43          ah(3,2)=ah(3,2)+ah(2,i)**2
44    20  ah(3,3)=ah(3,3)+ah(1,i)*ah(2,i)
45          ah(3,1)=sqrt(ah(3,1))
46          ah(3,2)=sqrt(ah(3,2))
47          ah(3,3)=ah(3,3)/(ah(3,1)*ah(3,2))
48          r=1./(sqrt(1.-ah(3,3)**2)*ah(3,2))
49          do 30 i=1,3
50          ah(1,i)=ah(1,i)/ah(3,1)
51    30  ah(2,i)=r*(ah(2,i)-ah(3,2)*ah(3,3)*ah(1,i))
52          ah(3,1)=ah(1,2)*ah(2,3)-ah(1,3)*ah(2,2)
53          ah(3,2)=ah(2,1)*ah(1,3)-ah(1,1)*ah(2,3)
54          ah(3,3)=ah(1,1)*ah(2,2)-ah(1,2)*ah(2,1)
55          return
56    c
57          end

NUMBER OF ERRORS =  0  NUMBER OF WARNINGS =  0
```

```
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Thu Jul 26 14:20:26 1990


 1  c  main and zz03 updated 9/4/80 by p. shimp to handle
 2  c  processing of a-plates
 3  c
 4        common /blk1/ xh(3),ah(3,3),xt(3),at(3,3)
 5        common /blk2/ xo(3,2),xs(3,2),c(3,3,2)
 6        common /c1/ nsub,nmnt,dat,blk,not,sday,syear,eday,eyear
 7  c
 8        character*6 ksubj,nsub,dat,blk
 9        character*6 not(9)
10        character*1 pcode
11        real w(3), p(4), pp(3,4)
12        integer jp(3)
13        real xp(2,2), x(3,13), xx(3)
14        real xtp(4)
15        real sp(2,2,13), er(13)
16        real xk(3,3), x1(3,3), x2(3,3)
17        real xpn(6)
18  c
19  c  the variables day and year refer to date of x-ray
20     integer day,year
21  c  The variables sday, syear, eday & eyear
22  c  are the start date and end date for the data.
23     integer date,sday,syear,eday,eyear
24  c
25        real spi(4,13)
26        equivalence (sp(1,1,1),spi(1,1))
27  c
28        data x1 /0.,0.,0.,6.286,-6.286,0.,6.286,6.286,0./
29        data x2 /-.3556,0.,.175,5.9304,-6.286,.175,5.9304,6.2 86,.175/
30  c
31  c  assign a unit number to the input and output files
32        open(10,file='input')
33        open(11,file='output')
34  c
35  10 continue
36  c
37  c  put terminal in 'caps' mode.........
38        call caps
39  c
40  c  request user input.........
41  c
42        write(6,*) 'enter subject number (a6 format)'
43        read(5,536) nsub
44        write(6,*) 'enter date of xray (MON YR  a6 format)'
45        read(5,536) dat
46        write(6,*) 'enter Julian date of xray (i5 format)'
47        read(5,565) idate
48  c
49  c.....read data from input file ........
50  c
51        read(10,535) ksubj,date,mmount,nmount,sday,syear,eday ,eyear
52  c
53  c
54  c.....check for correct input data......
55        if(ksubj.ne.nsub) go to 525
56        if(date.ne.idate) go to 12
57        go to 18
58  12 write(6,15)
```

```
15 format('Dates do not match. Enter Y to continue, N to stop.')
      read(5,540) pcode
      if(pcode.ne.'Y') go to 530
18 continue
c
c.....initialize the variable 'blk'
      blk='  '
c
      c.....process the data........
c
      write(6,*) 'enter pcode (A for a-plate or T for t-plate)'
      read (5,540) pcode
      if (pcode.ne.'A'.and.pcode.ne.'T') print 550
      if (pcode.ne.'A'.and.pcode.ne.'T') stop 1
      write(6,*) 'enter xray Julian date'
      read (5,545) day,year
      d=year*1000+day
      do 30 i=1,3
      do 30 j=1,3
      if (pcode.eq.'A') go to 20
      xk(i,j)=x1(i,j)
      go to 30
20  xk(i,j)=x2(i,j)
30  continue
      if (pcode.ne.'A') go to 35
c  in the event x-ray was taken after jan 1,1981 change z component
c  to.238 for A plates only
      if (d.lt. 81001) go to 35
      do 32 i=1,3
      xk(3,i)=.238
      32  continue
35  call prism2 (xo,xs,c)
40  write(6,555)
      read(5,560) jo,kk
      if(kk.eq.9) go to 530
      if(kk.eq.7) go to 10
      if (kk.eq.3) go to 220
      if (kk.eq.4) go to 450
c
c.....mouth data calculations
c
       write(6,*) 'enter comments for head data (9a6 format)'
       read(5,575) not
       nmnt=mmount
       write (11,580)
       write (11,590) nsub,nmnt,dat,(not(j),j=1,9)
       write(11,630)
       write(11,640)
       write(11,650)
       write(11,660)
       write(11,820)
       write(11,670)
 c
       do 50 j=1,4
       read(10,620) (spi(j,i),i=1,7)
       do 50 i=1,7
       spi(j,i)=spi(j,i)*2.54
 50  continue
       c
       c  interchange ltp and rtp coordinates when processing a-plate
       if (pcode.ne.'A') go to 70
       do 60 j=1,4
```

```
121         t=spi(j,6)
122         spi(j,6)=spi(j,7)
123         spi(j,7)=t
124   60  continue
125   70 continue
126         call rlswch (1,8,sp)
127         call rlswch (3,10,sp)
128         call rlswch (6,12,sp)
129         do 210 i=1,13
130         call pxry2 (x(1,i),sp(1,1,i),er(i),xtp)
131         if (i.eq.1) go to 80
132         if (i.eq.2) go to 90
133         if (i.eq.3) go to 100
134         if (i.eq.4) go to 110
135         if (i.eq.5) go to 120
136         if (i.eq.6) go to 130
137         if (i.eq.7) go to 140
138         if (i.eq.8) go to 150
139         if (i.eq.9) go to 160
140         if (i.eq.10) go to 170
141         if (i.eq.11) go to 180
142         if (i.eq.12) go to 190
143         if (i.eq.13) go to 200
144   80  write(11,680) (spi(j,i),j=1,4),(x(ii,i),ii=1,3),er(i)
145           go to 210
146   90  write(11,690) (spi(j,i),j=1,4),(x(ii,i),ii=1,3),er()
147           go to 210
148   100  write(11,700) (spi(j,i),j=1,4),(x(ii,i),ii=1,3),er(i)
149           go to 210
150   110  write(11,710) (spi(j,i),j=1,4),(x(ii,i),ii=1,3),er(i)
151           go to 210
152   120  write(11,720) (spi(j,i),j=1,4),(x(ii,i),ii=1,3),er(i)
153           go to 210
154   130  write(11,730) (spi(j,i),j=1,4),(x(ii,i),ii=1,3),er(i)
155           go to 210
156   140  write(11,740) (spi(j,i),j=1,4),(x(ii,i),ii=1,3),er(i)
157           go to 210
158   150  write(11,750)
159           write(11,760) (spi(j,i),j=1,4),(x(ii,i),ii=1,3),er(i)
160           go to 210
161   160  write(11,770) (spi(j,i),j=1,4),(x(ii,i),ii=1,3),er(i)
162           go to 210
163   170  write(11,780) (spi(j,i),j=1,4),(x(ii,i),ii=1,3),er(i)
164           go to 210
165   180  write(11,790) (spi(j,i),j=1,4),(x(ii,i),ii=1,3),er(i)
166           go to 210
167   190  write(11,800) (spi(j,i),j=1,4),(x(ii,i),ii=1,3),er(i)
168           go to 210
169   200  write(11,810) (spi(j,i),j=1,4),(x(ii,i),ii=1,3),er(i)
170   210  continue
171           call option (1,8,er,x,jo)
172           call option (3,10,er,x,jo)
173           call option (6,12,er,x,jo)
174           if (pcode.eq.'A') write(11,850)
175           call pobkg (x(1,5),xk,3,xt,at)
176           call htrans (x)
177           write (11,580)
178           write (11,600) nsub,nmnt,dat
179           write (11,610) (not(j),j=1,9)
180           call cdntpt
181           if (kk.eq.2) go to 40
182   c
```

```
183  c.....neck data calculations
184  c
185  220 continue
186        nmnt=nmount
187        write(6,*) 'enter comments for neck data  (9a6 format)'
188        read(5,575) not
189        write(6,*) 'enter block or noblock (a6 format)'
190        read(5,536) blk
191        write (11,860)
192        write (11,600) nsub,nmnt,dat
193        write (11,610) (not(j),j=1,9)
194  c
195  c.....read the required data
196  c
197        do 230 j=1,4
198        read(10,620) (spi(j,i),i=1,5)
199        do 230 i=1,5
200        spi(j,i)=spi(j,i)*2.54
201  230  continue
202        call rlswch (4,6,sp)
203        sc1=0.
204        sc2=0.
205        write(11,630)
206        write(11,640)
207        write(11,650)
208        write(11,660)
209        write(11,820)
210        write(11,670)
211        do 310 i=1,7
212        call pxry2 (x(1,i),sp(1,1,i),er(i),xtp)
213        if (i.gt.5) sc2=sc2+sp(2,2,i)-xtp(4)
214        if (i.eq.4.or.i.eq.5) sc2=sc2-sp(2,2,i)+xtp(4)
215        if (i.lt.6) sc1=sc1+sp(2,2,i)-xtp(4)
216        if (i.eq.1) go to 240
217        if (i.eq.2) go to 250
218        if (i.eq.3) go to 260
219        if (i.eq.4) go to 270
220        if (i.eq.5) go to 280
221        if (i.eq.6) go to 290
222        if (i.eq.7) go to 300
223  240  write(11,870) (spi(j,i),j=1,4),(x(ii,i),ii=1,3),er(i)
224         go to 310
225  250  write(11,880) (spi(j,i),j=1,4),(x(ii,i),ii=1,3),er(i)
226         go to 310
227  260  write(11,890) (spi(j,i),j=1,4),(x(ii,i),ii=1,3),er(i)
228         go to 310
229  270  write(11,900) (spi(j,i),j=1,4),(x(ii,i),ii=1,3),er(i)
230         go to 310
231  280  write(11,910) (spi(j,i),j=1,4),(x(ii,i),ii=1,3),er(i)
232         go to 310
233  290  write(11,750)
234         write(11,920) (spi(j,i),j=1,4),(x(ii,i),ii=1,3),er(i)
235         go to 310
236  300  write(11,930) (spi(j,i),j=1,4),(x(ii,i),ii=1,3),er(i)
237  310  continue
238         call option (4,6,er,x,jo)
239         ai=er(4)**2+er(5)**2-er(6)**2-er(7)**2
240         if (ai.gt.0.) sc1=sc1+sc2
241         call pobkg (x(1,3),xk,3,xt,at)
242         read(10,620) xp
243         do 320 i=1,2
244         do 320 j=1,2
```

```
245         xp(i,j)=xp(i,j)*2.54
246         320  continue
247         write (11,940) xp
248         ah(1,1)=-xs(3,1)*(xp(2,2)-xp(2,1))
249         ah(1,2)=xs(3,1)*(xp(1,2)-xp(1,1))
250         ah(1,3)=(xs(1,1)-xp(1,1))*(xp(2,2)-xp(2,1))-(xs(2,1)-xp(2,1))*(xp(
251        11,2)-xp(1,1))
252         do 330 i=1,3
253         xx(i)=x(i,2)-x(i,1)
254         ah(3,i)=0.
255         do 330 j=1,3
256         330  ah(3,i)=c(j,i,1)*ah(1,j)+ah(3,i)
257         ah(2,1)=ah(3,2)*xx(3)-ah(3,3)*xx(2)
258         ah(2,2)=ah(3,3)*xx(1)-ah(3,1)*xx(3)
259         ah(2,3)=ah(3,1)*xx(2)-ah(3,2)*xx(1)
260         ai=0.
261         do 340 i=1,3
262  340  ai=ai+ah(2,i)**2
263         ai=sqrt(ai)
264         do 350 i=1,3
265         1  350  ah(2,i)=ah(2,i)/ai
266  c
267         read(10,620) (xpn(k),k=1,6)
268         xp(1,1)=xpn(1)
269         xp(2,1)=xpn(2)
270         xp(1,2)=(xpn(3)+xpn(5))/2.0
271         xp(2,2)=(xpn(4)+xpn(6))/2.0
272  c
273         do 360 i=1,2
274  do 360 j=1,2
275         xp(i,j)=xp(i,j)*2.54
276  360  continue
277         write (11,960) xp
278         do 370 ill=1,2
279         370  xp(2,ill)=xp(2,ill)-sc1/5.
280         g1=0.
281         do 390 i=1,3
282         g3=x(i,1)
283         xx(i)=0.
284         do 380 j=1,3
285         xx(i)=xx(i)+ah(2,j)*c(i,j,2)
286  380  g3=g3+c(j,i,2)*(xo(j,2)-xs(j,2))
287  390  g1=g1+g3*ah(2,i)
288         do 420 i=1,2
289         ga=g1/((xp(1,i)-xs(1,2))*xx(1)+(xp(2,i)-xs(2,2))*xx(2)-xs(3,2)*x
290         1x(3))
291         do 400 j=1,2
292  400  x(j,8)=ga*(xp(j,i)-xs(j,2))+xs(j,2)
293         x(3,8)=(1.-ga)*xs(3,2)
294         l=i+5
295         do 410 j=1,3
296         x(j,l)=0.
297         do 410 k=1,3
298  410  x(j,l)=(x(k,8)-xo(k,2))*c(k,j,2)+x(j,l)
299  420  write (11,970) (x(j,l),j=1,3)
300         ai=0.
301         do 430 i=1,3
302         xh(i)=x(i,6)
303         ah(1,i)=xh(i)-x(i,7)
304  430  ai=ai+ah(1,i)**2
305         ai=sqrt(ai)
306         do 440 i=1,3
```

```
307         440  ah(1,i)=ah(1,i)/ai
308         ah(3,1)=ah(1,2)*ah(2,3)-ah(1,3)*ah(2,2)
309         ah(3,2)=ah(2,1)*ah(1,3)-ah(1,1)*ah(2,3)
310         ah(3,3)=ah(1,1)*ah(2,2)-ah(1,2)*ah(2,1)
311         write (11,860)
312         write (11,600) nsub,nmnt,dat
313         write (11,610) (not(j),j=1,9)
314         call cdntpt
315         go to 40
316   c
317   c.....pelvic data calculations
318   c
319   450 continue
320         write (11,980)
321
322         do 460 k=1,4
323   460  pp(j,k)=0.
324   470 do 480 j=1,4
325   480  read (10,620) (spi(j,i),i=1,6)
326         do 490 i=1,4
327         write (11,840) i,(spi(j,i),j=1,4)
328         call pxry2 (x(1,i),sp(1,1,i),er(i),xtp)
329   490  write (11,830) (x(ii,i),ii=1,3),er(i)
330         call htrans (x)
331         do 520 i=1,2
332         p(1)=(sp(2,i,6)-sp(2,i,5))*xs(3,i)
333         p(2)=(sp(1,i,5)-sp(1,i,6))*xs(3,i)
334         p(3)=(sp(1,i,5)-xs(1,i))*(sp(2,i,6)-xs(2,i))-(sp(2,i,5)-xs(2,i))
335         1*(sp(1,i,6)-xs(1,i))
336         p(4)=0.
337         do 500 j=1,3
338         p(4)=p(4)+p(j)*(xs(j,i)-xo(j,i))
339         w(j)=0.
340         do 500 k=1,3
341   500  w(j)=w(j)+p(k)*c(k,j,i)
342         do 510 j=1,3
343         p(4)=p(4)-w(j)*xh(j)
344         p(j)=0.
345         do 510 k=1,3
346   510  p(j)=p(j)+ah(j,k)*w(k)
347         write (11,990) p
348         do 520 k=1,3
349         do 520 j=1,4
350   520  pp(k,j)=pp(k,j)+p(k)*p(j)
351         read (5,1000) jj
352         if (jj.ne.0) go to 470
353         call axeb (pp,3,4,jp)
354         write (11,1010) (pp(j,4),j=1,3)
355         go to 40
356   c
357   c.....Output error message........
358   c
359   525 write(6,*) 'Incorrect Subject Id - Processing Stopped'
360   c
361   530 call capoff
362         stop
363   c
364   535 format(a6,1x,i5,1x,2(i4,1x),2(i3,i4))
365   536 format(a6)
366   540 format (a1)
367   545 format(i3,i2)
368   550 format (1x,'plate code invalid, check first input card'/1x,'it
```

```
     1should contain an a or t in column 1')
 555 format('enter option code jo and processing code kk (2i1) format'/
     *'jo = 1 to exercise the option (standard operation -always 1)'/
     *'jo = any other number not to exercise the option'/
     *'kk = 1 process head and neck data'/
     *'kk = 2 process head data only'/
     *'kk = 3 process neck data only'/
     *'kk = 4 process pelvic data only'/
     *'kk = 7 redo program'/
     *'kk = 9 end program')
 560 format (2i1)
 565 format (i5)
 570 format (a6,i4,10a6)
 575 format (9a6)
 580 format ('1  head anatomical to tee-plate transformation ')
 590 format ('  subject ',a6,'  mount ',i4,'  date ',a6,'  notes '
     19a6)
 600 format ('  subject ',a6,'  mount ',i4,'  date ',a6)
 610 format (10x,'  notes  ',9a6)
 620 format (7(f7.3,1x))
 630 format (1h0,'bee bee id i  measured x-ray coordinates
     1 i  lab coordinates  i  sum of the squares of the')
 640 format (12x,'i',42x,'i',31x,'i  difference between the')
 650 format (12x,'i',42x,'i',31x,'i  measured and best estimate')
 660 format (12x,'i',8x,'ap',19x,'lat',10x,'i',31x,'i  of x-ray coordin
     1ates')
 670 format  (1h0,11x,'i',4x,'x',10x,'y',10x,'x',8x,'y',6x'i',4x,'x',9x
     1,'y',9x,'z',6x,'i',4x,'e')
 680 format (1h,1x,'1 r.audit  ',f8.4,2x,f8.4,4x,f8.4,2x,f8.4,4x,f8.4,
     12x,f8.4,2x,f8.4,4x,f8.4)
 690 format (2x,'2 l.audit  ',f8.4,2x,f8.4,4x,f8.4,2x,f8.4,4x,f8.4,2x,f
     18.4,2x,f8.4,4x,f8.4)
 700 format (2x,'3 r.orbit  ',f8.4,2x,f8.4,4x,f8.4,2x,f8.4,4x,f8.4,2x,f
     18.4,2x,f8.4,4x,f8.4)
 710 format (2x,'4 l.orbit  ',f8.4,2x,f8.4,4x,f8.4,2x,f8.4,4x,f8.4,2x,f
     18.4,2x,f8.4,4x,f8.4)
 720 format (2x,'5 c.t-plt  ',f8.4,2x,f8.4,4x,f8.4,2x,f8.4,4x,f8.4,2x,f
     18.4,2x,f8.4,4x,f8.4)
 730 format (2x,'6 r.t-plt  ',f8.4,2x,f8.4,4x,f8.4,2x,f8.4,4x,f8.4,2x,f
     18.4,2x,f8.4,4x,f8.4)
 740 format (2x,'7 l.t-plt  ',f8.4,2x,f8.4,4x,f8.4,2x,f8.4,4x,f8.4,2x,f
     18.4,2x,f8.4,4x,f8.4)
 750 format (1h0,14x,'right/left switch follow below')
 760 format (1h0,1x,'8 r.audit  ',f8.4,2x,f8.4,4x,f8.4,2x,f8.4,4x,f8.4,
     12x,f8.4,2x,f8.4,4x,f8.4)
 770 format (2x,'9 l.audit  ',f8.4,2x,f8.4,4x,f8.4,2x,f8.4,4x,f8.4,2x,f
     18.4,2x,f8.4,4x,f8.4)
 780 format (1x,'10 r.orbit  ',f8.4,2x,f8.4,4x,f8.4,2x,f8.4,4x,f8.4,2x,
     1f8.4,2x,f8.4,4x,f8.4)
 790 format (1x,'11 l.orbit  ',f8.4,2x,f8.4,4x,f8.4,2x,f8.4,4x,f8.4,2x,
     1f8.4,2x,f8.4,4x,f8.4)
 800 format (1x,'12 r.t-plt  ',f8.4,2x,f8.4,4x,f8.4,2x,f8.4,4x,f8.4,2x,
     1f8.4,2x,f8.4,4x,f8.4)
 810 format (1x,'13 l.t-plt  ',f8.4,2x,f8.4,4x,f8.4,2x,f8.4,4x,f8.4,2x,
     1f8.4,2x,f8.4,4x,f8.4)
 820 format (12x,'i',42x,'i',31x,'i')
 830 format (5x,4f15.4)
 840 format (1h0,2x,i2,4f15.4)
 850 format (///1x,'note:when processing data from a-plate, ltp and rtp
     1'1x,'are interchanged from the way in which they were entered to'/
     25x,'account for position of a-plate ')
 860 format ('1  t-1 anatomical to tee-plate transformation ')
```

```
431   870 format (1h0,1x,'1 p-spine  ',f8.4,2x,f8.4,4x,f8.4,2x,f8.4,4x,f8.4,
432       12x,f8.4,2x,f8.4,4x,f8.4)
433   880 format (2x,'2 s-notch  ',f8.4,2x,f8.4,4x,f8.4,2x,f8.4,4x,f8.4,2x,f
434       18.4,2x,f8.4,4x,f8.4)
435   890 format (2x,'3 c.t-plt  ',f8.4,2x,f8.4,4x,f8.4,2x,f8.4,4x,f8.4,2x,f
436       18.4,2x,f8.4,4x,f8.4)
437   900 format (2x,'4 r.t-plt  ',f8.4,2x,f8.4,4x,f8.4,2x,f8.4,4x,f8.4,2x,f
438       18.4,2x,f8.4,4x,f8.4)
439   910 format (2x,'5 l.t-plt  ',f8.4,2x,f8.4,4x,f8.4,2x,f8.4,4x,f8.4,2x,f
440       18.4,2x,f8.4,4x,f8.4)
441   920 format (1h0,1x,'6 r.t-plt  ',f8.4,2x,f8.4,4x,f8.4,2x,f8.4,4x,f8.4,
442       12x,f8.4,2x,f8.4,4x,f8.4)
443   930 format (2x,'7 l.t-plt  ',f8.4,2x,f8.4,4x,f8.4,2x,f8.4,4x,f8.4,2x,f
444       18.4,2x,f8.4,4x,f8.4)
445   940 format (22h0  articular facets,4f10.4)
446   960 format (23h0  lateral projection,4f10.4)
447   970 format (5x,3f15.4)
448   980 format ('1  c.g. routine')
449   990 format (5x,4f14.6)
450   1000 format (i2)
451   1010 format (5x,3f14.6)
452   1020 format (a6,i5,a5,i2,2i7,20f7.3)
453   c
454         end

NUMBER OF ERRORS =  0  NUMBER OF WARNINGS =  0
```

```
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Thu Jul 26 14:20:55 1990

 1          subroutine option (j,k,er,x,jo)
 2    c
 3    c  subroutine option
 4    c
 5    c
 6    c  This subroutine compares the residual error associated with the
 7    c  measured definition of the location of right and left bee bee's, with
 8    c  the errors associated with subroutine rlswch's definition of right
 9    c  and left bee bee's. Finally it states the option with least error and
10    c  if told to do so will exercise the option.
11    c
12    c  The options are
13    c  1. option j vs. k not indicated
14    c  2. option j vs. k indicated but ignored
15    c  3. option j vs. k indicated and exercised
16    c
17    c  Input consist of
18    c  j  =  the number of the right-side bee bee's as obtained from
19    c        lateral view measurements
20    c
21    c  k  =  the number of the right-side bee bee's so labeled by
22    c        subroutine rlswch has identical x-ray coordinates as the
23    c        measured labeled left side bee bee
24    c
25    c  er =  the sum of the squares of the difference between the
26    c        'measured' and 'calculated' ap and lateral x-ray
27    c        coordinates of the bee bee under scrunity.
28    c
29    c  x  =  calculated in subroutine pxryz and is the best least squares
30    c        lab coordinates for the bee bee under scrutiny.
31    c
32    c  jo =  code which determines if an option is to be exercised.
33    c
34    c
35          real x(3,13),er(13)
36    c
37    c  assign a unit number to the output file
38          open(11,file='output')
39    c
40          r=er(k)*er(k)+er(k+1)*er(k+1)-er(j)*er(j)-er(j+1)*er(j+1)
41          if (r.gt.0.) go to 30
42          if (jo.ne.1) go to 20
43          write (11,40) j,k
44          l=j+1
45          do 10 i=1,3
46          x(i,j)=x(i,k)
47    10   x(i,l)=x(i,k+1)
48          return
49    20 write (11,50) j,k
50          return
51    30 write (11,60) j,k
52          return
53    c
54    40 format (9h  option,i2,4h vs,i2,24h indicated and exercised)
55    50 format (9h  option,i2,4h vs,i2,23h indicated but ignored)
56    60 format (9h  option,i2,4h vs,i2,15h not indicated)
57    c
58          end
NUMBER OF ERRORS =  0  NUMBER OF WARNINGS =  0
```

```
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 1          subroutine pobkg (x,xx,ii,pp,a)
 2    c
 3    c  subroutine pobkg
 4    c
 5    c
 6    c  This subroutine calculates the vector defining the
 7    c  instrument origin pp lab coordinates and also calculates
 8    c  the transformation matrix [instr/lab]
 9    c  a(i,j) = at(i,j) of main program.
10    c
11    c  input consist of:
12    c  x(3,3)  = best least squares coordinates of the center, right,
13    c            and left t-plate bee bee's in the lab coordinate
14    c            system as calculated in subroutine pxryz
15    c
16    c  ii      = 3 the number of bee bee's on the t-plate
17    c
18    c  xx(3,3) = xk in main program and is the location of the 3
19    c            instrument bee bee's in the instrument coordinate system.
20    c
21    c  output consist of:
22    c  pp(i)   = vector defining the instrument origin in lab coordinates
23    c            also xt(i) in the main program and in subroutine cdntpt
24    c
25    c  a(i,j)  = transformation matrix which takes a vector from the
26    c            instrument coordinate system and puts it in the lab
27    c            coordinate system. Also called at(j,j) in the main program
28    c
29          real xp(3)
30          real x(3,3), xx(3,3), pp(3), a(3,3), xm(3,3)
31    c
32    c  assign a unit number to the output file
33          open(11,file='output')
34    c
35          write(11,440)
36          write(11,120)
37          write(11,130)
38          write(11,140)
39          write(11,150)
40          write(11,160)
41          write(11,170)
42          write(11,180)
43          write(11,190)
44          write(11,200)
45          write(11,210)
46          write(11,220)
47          write(11,230)
48          write(11,240)
49          write(11,250)
50          write(11,260)
51          write(11,270)
52          write(11,280)
53          write(11,290)
54          write(11,300)
55          write(11,310)
56          write(11,320)
57          write(11,330)
58          write(11,340)
```

```
      write(11,350)
      write(11,360)
      write(11,370)
      write(11,380)
      write(11,390)
      write(11,400)
      write(11,410)
      write(11,420)
      write(11,430)
      write(11,110) xx
c
c
      do 20 i=1,3
      xp(i)=0.
      pp(i)=0.
      do 10 j=1,ii
      pp(i)=pp(i)+x(i,j)
10    xp(i)=xp(i)+xx(i,j)
      xp(i)=xp(i)/float(ii)
20    pp(i)=pp(i)/float(ii)
      do 40 i=1,3
      do 30 j=1,3
      a(i,j)=0.
      xm(i,j)=0.
      do 30 k=1,ii
30    xm(i,j)=xm(i,j)+(x(i,k)-pp(i))*(xx(j,k)-xp(j))
40    a(i,i)=1.
      do 80 ijk=1,10
      w=atan2((xm(3,2)-xm(2,3)),(xm(2,2)+xm(3,3)))
      c=cos(w)
      s=sin(w)
      do 50 k=1,3
      r=a(2,k)
      a(2,k)=c*r-s*a(3,k)
      a(3,k)=s*r+c*a(3,k)
      r=xm(k,2)
      xm(k,2)=c*r-s*xm(k,3)
50    xm(k,3)=s*r+c*xm(k,3)
      w=atan2((xm(1,3)-xm(3,1)),(xm(1,1)+xm(3,3)))
      c=cos(w)
      s=sin(w)
       do 60 k=1,3
       r=a(1,k)
       a(1,k)=c*r+s*a(3,k)
       a(3,k)=c*a(3,k)-s*r
       r=xm(k,1)
       xm(k,1)=c*r+s*xm(k,3)
       60  xm(k,3)=c*xm(k,3)-s*r
       w=atan2((xm(2,1)-xm(1,2)),(xm(1,1)+xm(2,2)))
       c=cos(w)
       s=sin(w)
       do 70 k=1,3
       r=a(1,k)
       a(1,k)=c*r-s*a(2,k)
       a(2,k)=c*a(2,k)+s*r
       r=xm(k,1)
       xm(k,1)=c*r-s*xm(k,2)
70    xm(k,2)=c*xm(k,2)+s*r
      r=(abs(xm(2,3)-xm(3,2))+abs(xm(1,2)-xm(2,1))+abs(xm(1,3)-xm(3,1)
      1))/(xm(1,1)+xm(2,2)+xm(3,3))
      if (r.ge.0..and.r.lt..000001) go to 90
80    continue
```

```
 90 do 100 i=1,3
       do 100 j=1,3
100  pp(i)=pp(i)-a(i,j)*xp(j)
       return
c
110 format (///60x,'x  y  z'//48x,'bb 1  ',3f9.4//6x,'loca
    ion of bee bees in instrumentation:  bb 2  ',3f9.4//48x,'bb 3  ',
      3f9.4)
120 format (//50x,'/-----------\')
130 format (47x,'//',17x,'\')
140 format (44x,'/',23x,'\')
150 format (42x,'/',27x,'\')
160 format (40x,'/',30x,'\')
170 format (38x,'/',33x,'\')
180 format (37x,'/',35x,'\')
190 format (36x,'/',37x,'\')
200 format (35x,'/',39x,'\')
210 format (34x,'/',41x,'\')
220 format (33x,'//',6x,'/----\',7x,'-----',5x,'/----\',6x,'\\')
230 format (33x,'/',6x,'1',6x,'1',6x,'1+++1',4x,'1',6x,'1',5x,'\\')
240 format (9x,'+ z  out of paper',7x,'/',7x,'\----/',7x,'1+ +1',5x,'\
    ',7x,'\',12x,'\')
250 format (32x,'//',20x,'1+1+1---------------------------------  + y
    direction')
260 format (32x,'1',21x,'1+++1',19x,'\',11x,'/')
270 format (32x,'1',21x,'1 1 1',19x,'1')
280 format (32x,'1',21x,'1 1 1',19x,'1')
290 format (32x,'1',21x,'1 1 1',19x,'1')
300 format (32x,'1',21x,'1 1 1',19x,'1')
310 format (33x,'\',20x,'1 1 1',19x,'/')
320 format (54x,'1 1 1',18x,'/')
330 format (54x,'1 1 1')
340 format (54x,'1 1 1')
350 format (34x,'---------------------1 1 1----------------------')
360 format (34x,'1  +++++',14x,'1',15x,'++++++ 1')
370 format (34x,'1  + 2 +',14x,'1',15x,'+  3 + 1')
380 format (34x,'1  +++++',14x,'1',15x,'++++++ 1')
390 format (34x,'1---------------------1-----------------------')
400 format (5(56x,'1'/),56x,'1')
410 format (54x,'\ 1 /')
420 format (55x,'\1/')
430 format (53x,'+ x  direction')
440 format (1h1,'plexiglass t-plate coordinate system-orientation and
    ocation of bee bees')
c
       end

NUMBER OF ERRORS =  0  NUMBER OF WARNINGS =  0
```

```
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Thu Jul 26 14:21:16 1990


 1          subroutine prism2 (xop,xsp,cp)
 2  c
 3  c
 4  c  This subroutine establishes the lab coordinate system and
 5  c  calculates both the ap and lateral camera orientations and
 6  c  positions in the lab.
 7  c
 8  c  Inputs are all initial guesses
 9  c  xo = vector from lab to x-ray origin in x-ray coordinates
10  c
11  c  xs = vector from source origin to x-ray origin in x-ray coordinates
12  c
13  c  c = transformation matrix from [lab/xray]?
14  c
15  c  Outputs are the best estimates of the three inputs above?
16  c
17  c
18  c
19  c  Revised December 1987
20  c
21  c  The following assumptions were made:
22  c
23  c  (1) xs is the same for ap and lateral calibration and is
24  c      constant for all runs.
25  c      The value of xs: 0.0, 0.0, 150.
26  c
27  c  (2) xo is different for ap and lateral calibration but is
28  c      constant for all runs.
29  c      The values of xo are: (ap) 20., 0.0, 10.; (lat) 0.0, 0.0, 10.
30  c
31  c  (3) c is different for ap and lateral calibrations but is
32  c      constant for all runs.
33  c      The values of c are:
34  c  (ap)  (lat)
35  c              -1.0, 0.0, 0.0                          0.0, 0.0, 1.0
36  c               0.0, 0.0, 1.0                          1.0, 0.0, 0.0
37  c               0.0, 1.0, 0.0                          0.0, 1.0, 0.0
38  c
39  c*IF ANY OF THESE ASSUMPTIONS ARE WRONG, THIS ROUTINE MUST BE MODIFIED*
40  c
41  c
42  c
43        real xop(3,2), xsp(3,2), cp(3,3,2), xpp(2,13,2), pxp(2,2)
44        real xt(3,13), a(9,10), xp(2,13), c(3,3), xo(3), xs(3), rt(3)
45        real w(10),cc(3,3),xxo(3),xxs(3)
46        integer ja(9)
47  c
48        data cc /-1.0,0.0,0.0,0.0,0.0,1.0,0.0,1.0,0.0/
49        data xxo /20.0,0.0,10.0/
50        data xxs /0.0,0.0,150.0/
51        data xt /5.08,0.,5.08,25.4,0.,5.08,25.4,0.,25.4,5.08,0.,25.4,0.,6.
52       20,25.4,0.,5.08,5.08,0.,25.4,5.08,0.,25.4,25.4,5.08,25.4,15.24,15.
53       24,15.24,15.24,25.4,5.08,15.24,15.24,15.24,5.08,15.24,15.24,25.4/
54  c
55  9  format(3(f7.3,2x))
56  c
57  c  assign a unit number to the input file
58        open(10,file='input')
```

```
59          open(11,file='output')
60    c
61          write (11,230)
62          jj=1
63    10   do 12 i=1,3
64          xo(i)=xxo(i)
65          xs(i)=xxs(i)
66          do 12 j=1,3
67          12   c(i,j)=cc(i,j)
68          if(jj.ne.2) go to 15
69          write(11,240)
70          xo(1)=0.0
71          c(1,1)=0.0
72          c(3,1)=1.0
73          c(1,2)=1.0
74          c(3,2)=0.0
75    15 do 20 i=1,13
76          do 20 j=1,2
77    20   xp(j,i)=999.
78    c
79    c   read the required input date
80    c
81          read(10,260) (xp(1,i),i=1,13)
82          read(10,260) (xp(2,i),i=1,13)
83    c
84          do 30 i=1,13
85          xp(1,i)=xp(1,i)*2.54
86          xp(2,i)=xp(2,i)*2.54
87    30   continue
88          nl=0
89    40 err=0.
90          do 50 i=1,9
91          ja(i)=0
92          do 50 j=1,10
93    50   a(i,j)=0.
94          do 100 i=1,13
95          if (xp(1,i).ge.99..or.xp(2,i).ge.99.) go to 100
96          do 60 j=1,3
97          rt(j)=0.
98          do 60 k=1,3
99    60   rt(j)=rt(j)+xt(k,i)*c(j,k)
100           w(1)=xs(3)/(xs(3)-rt(3)-xo(3))
101           w(2)=0.
102           w(3)=w(1)*(rt(1)+xo(1)-xs(1))/(xs(3)-rt(3)-xo(3))
103           w(4)=-w(1)*(rt(3)+xo(3))/xs(3)
104           w(5)=0.
105           w(6)=-w(3)*(rt(3)+xo(3))/xs(3)
106           w(7)=w(3)*rt(2)
107           w(8)=w(1)*rt(3)-w(3)*rt(1)
108           w(9)=-w(1)*rt(2)
109           w(10)=xp(1,i)-xs(1)-w(1)*(rt(1)+xo(1)-xs(1))
110           erp=w(10)**2
111           n=0.
112    70   do 80 k=1,10
113           do 80 j=1,9
114    80   a(j,k)=a(j,k)+w(k)*w(j)
115           err=err+w(10)**2
116           if (n.eq.1) go to 90
117           n=1
118           w(2)=w(1)
119           w(1)=0.
120           w(3)=w(2)*(rt(2)+xo(2)-xs(2))/(xs(3)-rt(3)-xo(3))
```

```
121         w(5)=w(4)
122         w(4)=0.
123         w(6)=-w(3)*(rt(3)+xo(3))/xs(3)
124         w(7)=w(3)*rt(2)-w(2)*rt(3)
125         w(8)=-w(3)*rt(1)
126         w(9)=w(2)*rt(1)
127         w(10)=xp(2,i)-xs(2)-w(2)*(rt(2)+xo(2)-xs(2))
128         erp=erp+w(10)**2
129         go to 70
130   90  if (nl.eq.20) write (11,270) i,xp(1,i),xp(2,i),erp
131   100  continue
132   call axeb (a,9,10,ja)
133   ao=0.
134   do 110 j=1,3
135   1  ao=ao+a(j+6,10)**2
136   1  xo(j)=xo(j)+a(j,10)
137   1  110  xs(j)=xs(j)+a(j+3,10)
138   ao=sqrt(ao)
139   if (ao.lt..25) go to 130
140   do 120 j=7,9
141   120  a(j,10)=a(j,10)*.25/ao
142   130 r=sqrt(1.-a(9,10)**2)
143   do 140 j=1,3
144   p=c(1,j)
145   c(1,j)=p*r-c(2,j)*a(9,10)
146   140  c(2,j)=p*a(9,10)+c(2,j)*r
147   r=sqrt(1-a(8,10)**2)
148   do 150 j=1,3
149   p=c(1,j)
150   c(1,j)=p*r+c(3,j)*a(8,10)
151   150  c(3,j)=r*c(3,j)-p*a(8,10)
152   r=sqrt(1-a(7,10)**2)
153   do 160 j=1,3
154   p=c(2,j)
155   c(2,j)=p*r-c(3,j)*a(7,10)
156   160  c(3,j)=p*a(7,10)+c(3,j)*r
157   write (11,280) c,xo,xs,err
158   nl=nl+1
159   if (nl.le.20) go to 40
160   do 170 i=1,3
161   xsp(i,jj)=xs(i)
162   xop(i,jj)=xo(i)
163   do 170 j=1,3
164   170  cp(i,j,jj)=c(i,j)
165   do 180 i=1,13
166   xpp(1,i,jj)=xp(1,i)
167   180  xpp(2,i,jj)=xp(2,i)
168   jj=jj+1
169   if (jj.lt.3) go to 10
170   write (11,290)
171   do 210 i=1,13
172   ptp=0.
173   do 190 j=1,2
174   do 190 k=1,2
175   ptp=ptp+xpp(j,i,k)
176   190  pxp(j,k)=xpp(j,i,k)
177   if (ptp.gt.99.) go to 210
178   call pxry2 (w(1),pxp,r,w(4))
179   erp=0.
180   do 200 j=1,3
181   200  erp=erp+(w(j)-xt(j,i))**2
182   write (11,300) i,(xt(j,i),j=1,3),(w(k),k=1,3),erp
```

```
183   210  continue
184   c
185   230 format ('1  set up parameters - a-p projection',a6)
186   240 format ('1  set up parameters - lateral projection',a6)
187   250 format (3f10.0)
188   260 format (13(f7.3,1x))
189   270 format (5x,i3,2f10.6,f10.7)
190   280 format (5x,9f10.5)
191   290 format ('1  back-check multiply acquired cal points'///)
192   300 format (5x,i3,6f10.4,f10.7)
193   c
194   end

NUMBER OF ERRORS =   0  NUMBER OF WARNINGS =   0
```

```
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 1          subroutine pxry2 (x,a,r,xr)
 2  c
 3  c  subroutine pxryz
 4  c
 5  c
 6  c  This subroutine calculates the best least square coordinates
 7  c  in the lab (x(i),i=1,2,3) consistent with the ap & lateral x-ray
 8  c  coordinates of all bee bee's and possible right-left ambiguities
 9  c  arising from the lateral x-ray view.
10  c
11  c  input consist of:
12  c  a(2,2)  = the ap,x; ap,y; lat,x; lat,y; measured x-ray coordinates
13  c            of the ith bee bee. i=1,7 for neck monut, i=1,13 for head
14  c            mount.  Also known a sp(2,2,13) in subroutine rlswch and
15  c            as spi(4,13) in the main program.
16  c
17  c  xo(3,2) = vectors from lab to x-ray origin (ap:lat) in x-ray coord's
18  c
19  c  xs(3,2) = vector from camera origin to x-ray origin in x-ray coord's
20  c
21  c  c(3,3,2)= transformation matricces from [lab/x-ray]ap:[lab/xray]lat.
22  c
23  c  output consist of:
24  c  x(3)  = best least squares estimate of bee bee in lab coordinates
25  c
26  c  r  = sum of the square of the error between the measured
27  c       x-ray coordinates and the x-ray coordinates obtained by
28  c       projection of the best least squares position of the bee
29  c       bee onto both x-ray film planes.
30  c
31  c  r  = [ap(x,y)measured-ap(x,y)theory]**2.0 +
32  c       [lat(x,y)measured-lat(x,y)theory]
33  c
34  c  xr(2,2) = the x-ray coordinates obtained by projection of the
35  c            calculated position of the bee bee onto the x-ray film
36  c            planes. It is called xtp(4) in the main program.
37  c            It is used in the neck calculations.
38  c
39  c  bench marks of intrest consist of:
40  c  x(1)  = x(1)+det(2)/det(1) the sum of the change in the x
41  c          component of the lab coordinates of the bee bee for each
42  c          iteration for the best coordinate calculation routine.
43  c
44  c  e  = the magnitude of the change squared of x(3) above,
45  c       calculated for each iteration of the best coordinates
46  c       routine.
47  c
48  c
49         common /blk2/ xo(3,2),xs(3,2),c(3,3,2)
50         real x(3), a(2,2), xr(2,2), w(4), gm(3,4), det(4), xx(3)
51         nc=0
52         do 10 i=1,3
53   10   x(i)=0.
54   20  do 30 i=1,3
55         do 30 j=1,4
56   30   gm(i,j)=0.
57         r=0.
58         nc=nc+1
```

```
59          do 60 i=1,2
60          do 40 j=1,3
61          xx(j)=xo(j,i)-xs(j,i)
62          do 40 k=1,3
63    40    xx(j)=xx(j)+c(j,k,i)*x(k)
64          do 60 j=1,2
65          w(4)=a(j,i)+xx(j)/xx(3)*xs(3,i)-xs(j,i)
66          r=r+w(4)**2
67          do 50 k=1,3
68    50    w(k)=-(c(j,k,i)-c(3,k,i)*xx(j)/xx(3))*xs(3,i)/xx(3)
69          do 60 k=1,3
70          do 60 l=1,4
71    60    gm(k,l)=gm(k,l)+w(k)*w(l)
72          do 80 i=1,4
73          det(i)=gm(1,1)*(gm(2,2)*gm(3,3)-gm(2,3)-gm(3,2))+gm(1,2)*(gm(2,3
74        1)*gm(3,1)-gm(2,1)*gm(3,3))+gm(1,3)*(gm(2,1)*gm(3,2)-gm(3,1)*gm(2,2
75        2))
76          if (i.eq.4) go to 80
77          do 70 k=1,3
78          e=gm(k,i)
79          gm(k,i)=gm(k,4)
80    70    gm(k,4)=e
81    80    continue
82          x(1)=x(1)+det(2)/det(1)
83          x(2)=x(2)-det(3)/det(1)
84          x(3)=x(3)+det(4)/det(1)
85          e=(det(2)**2+det(3)**2+det(4)**2)/det(1)**2
86          if (e.gt..00001.and.nc.le.10) go to 20
87          do 100 i=1,2
88          do 90 j=1,3
89          xx(j)=xo(j,i)-xs(j,i)
90    c
91    c
92    c where xo(j,i) = (lab origin - xray origin) in xray coordinates
93    c  xs(j,i) = (xray source - xray origin) in xray coordinates
94    c
95    c
96          do 90 k=1,3
97    90    xx(j)=xx(j)+c(j,k,i)*x(k)
98    c
99    c  xx(j) = (point - source) in xray coordinates
100         do 100 j=1,2
101         c
102   100   xr(j,i)=xs(j,i)-xx(j)/xx(3)*xs(3,i)
103   c
104   c  -xx(j)/xx(3)*xs(3,i) = (theoretical xray coordinates of a point
105   c  minus source coordinates) in xray system
106   c  xr(j,i) = theoretical xray coordinates
107   c
108         return
109   c
110         end

NUMBER OF ERRORS =  0  NUMBER OF WARNINGS =  0
```

```
FORTRAN 77/UX  HP92430A.07.04  COPYRIGHT HEWLETT-PACKARD CO. 1983.
Thu Jul 26 14:21:31 1990


 1          subroutine rlswch (j,k,sp)
 2    c
 3    c  subroutine rlswch
 4    c
 5    c
 6    c  This subroutine gathers the ap and lat x-ray coordinates of the
 7    c  anatomical instrument bee bee's. It then generates additional points
 8    c  by making an alternate switch of the possible ambiguities which
 9    c  could arise when varying certain bee bee locations on the lateral
10    c  x-rays.
11    c
12    c  input and output consist of:
13    c  sp(2,2,13) = t the first 28 elements of this array contain the
14    c                  measured coordinates of the ap and lat views of the
15    c                  the subject's bee bee's, and are passed to this
16    c                  subroutine from the main program. The last 24 elements
17    c                  array are empty and will receive the right-left/left-
18    c                  right switch of coordinates performed by this
19    c                  subroutine.
20    c
21    c  j  =            the index of the right side bee bee on the lateral
22    c  view as obtained from measurement.
23    c
24    c  k  = the index of the right-side bee bee so labeled by
25    c       this subroutine and has identical x-ray coordinates
26    c       as the measured labeled left side bb. A least square
27    c       solution with accompanying error for both labeled bee
28    c       bee's in lab coordinates is determined in subroutine
29    c       pxry2. If the proper switch is set in subroutine option
30    c       the discreptences will be automatically corrected there
31    c
32    c
33          real sp(2,2,13)
34          l=k+1
35          do 10 i=1,2
36          sp(i,1,k)=sp(i,1,j)
37          sp(i,2,k)=sp(i,2,j+1)
38          sp(i,1,l)=sp(i,1,j+1)
39    10   sp(i,2,l)=sp(i,2,j)
40          return
41    c
42          end

NUMBER OF ERRORS =  0 NUMBER OF WARNINGS = 0
```

# APPENDIX B

## Listing of "IOUPDATE"

```
echo Procedure to update xray input file and to execute main program
cp $1 input
cp output $2
cp update $3
echo Files Saved - Executing Main Xray-Anthropometry Program
mxray
```

# APPENDIX C

## Listing of "INPUT"

```
H00209 10888 1101 2201   0   0  0   0
 10.386   1.648   1.532  10.273 999.000 999.000 999.000 999.000   9.278   4.890
1.144   4.973   4.818
 -1.914  -1.944   6.812   7.015 999.000 999.000 999.000 999.000   2.285   2.327
2.359  -2.526   7.180
999.000 999.000 999.000 999.000   2.924   2.415  11.212  11.315  11.119   5.850
-.286   5.800   5.935
999.000 999.000 999.000 999.000   6.814  -1.942  -2.286   6.697   2.051   1.813
1.548  -3.216   6.883
   .712   6.362    .994   4.576   2.565   -.581   5.697
  3.036   3.823   4.461   4.814   5.660   2.627   2.389
  1.778   3.033   7.023   7.421  11.146  10.489  10.542
  2.356   3.491   3.935   4.366   5.072   1.787   1.945
  4.729   4.216   5.040   1.992   7.698
  1.597  -1.608   4.446   4.522   4.175
  6.308  11.900   -.370   2.328   3.053
  1.045  -1.989   4.237   4.010   3.804
  2.304   1.575   6.920   1.459
 10.223   -.059   6.750    .369   6.984    .860
```

# APPENDIX D

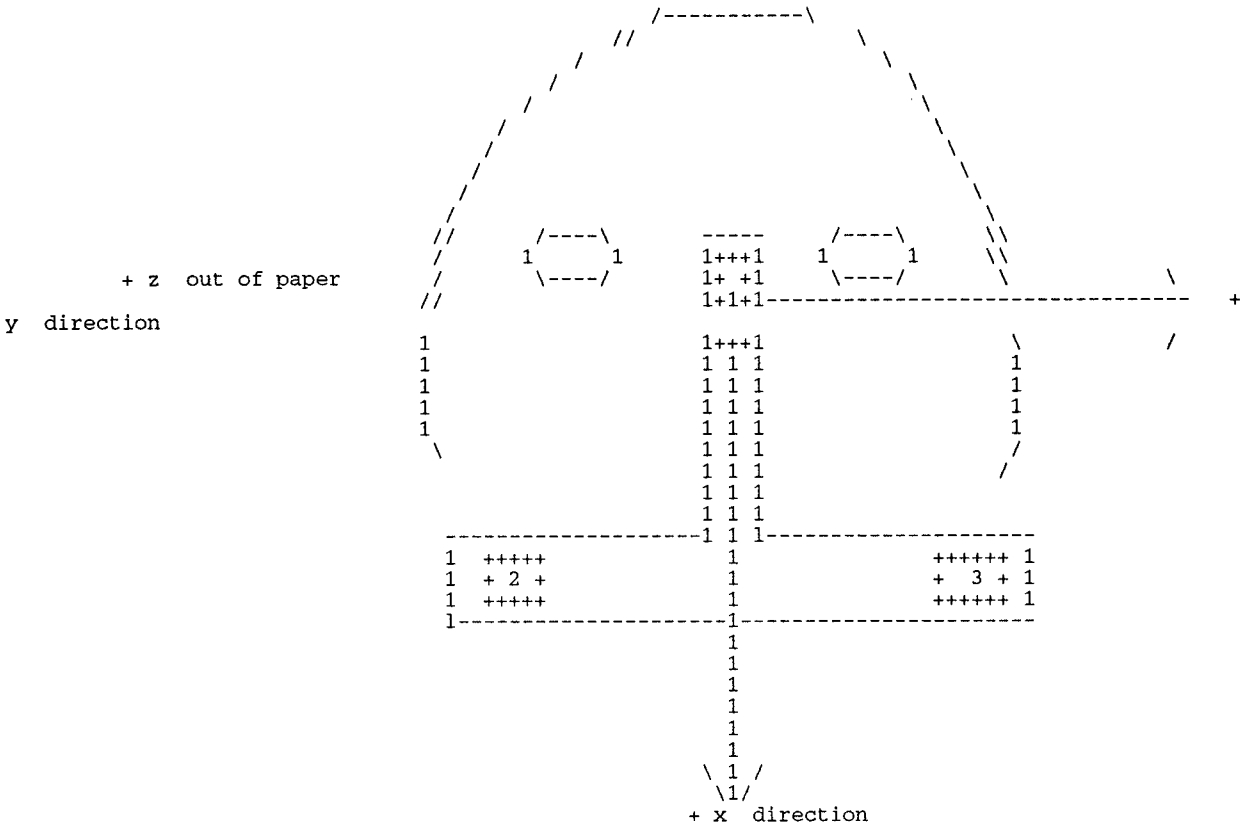
## Listing of "OUTPUT"

```
1     set up parameters - a-p projection
       -.99885   -.01122   -.04663   -.04612   -.04255    .99803   -.01318    .99903    .04199
      31.38578  -9.44438  14.62792  29.17912    .70755 173.346161816.69006
       -.98938   -.01484   -.14458   -.14440   -.01310    .98943   -.01658    .99980    .01082
      30.64409  -8.72047  19.82321  15.29855  7.45546 185.71568    .97425
       -.98711   -.01351   -.15944   -.15924   -.01517    .98712   -.01575    .99979    .01283
      29.98223  -8.62734  19.63002  11.52374  7.35874 184.20836    .66993
       -.98781   -.01232   -.15518   -.15487   -.02303    .98767   -.01574    .99966    .02084
      30.08084  -8.78918  19.42020  12.39414  5.87360 184.01617    .01011
       -.98702   -.01233   -.16015   -.15984   -.02284    .98688   -.01583    .99966    .02058
      29.97732  -8.78477  19.50641  11.44204  5.90834 184.14708    .00986
       -.98724   -.01202   -.15878   -.15845   -.02481    .98705   -.01581    .99962    .02259
      30.00607  -8.82524  19.45057  11.70691  5.53493 184.10239    .00981
       -.98704   -.01204   -.16004   -.15971   -.02468    .98685   -.01583    .99962    .02244
      29.97989  -8.82260  19.47390  11.46572  5.55905 184.13451    .00979
       -.98710   -.01196   -.15967   -.15933   -.02516    .98690   -.01582    .99961    .02293
      29.98773  -8.83229  19.45997  11.53778  5.46947 184.12390    .00979
       -.98705   -.01197   -.15998   -.15965   -.02511    .98685   -.01583    .99961    .02287
      29.98128  -8.83130  19.46601  11.47830  5.47863 184.13174    .00979
       -.98706   -.01195   -.15988   -.15955   -.02522    .98687   -.01583    .99961    .02299
      29.98337  -8.83362  19.46251  11.49755  5.45714 184.12914    .00979
       -.98705   -.01196   -.15996   -.15962   -.02521    .98686   -.01583    .99961    .02297
      29.98177  -8.83331  19.46407  11.48277  5.46002 184.13101    .00979
       -.98706   -.01195   -.15993   -.15960   -.02523    .98686   -.01583    .99961    .02300
      29.98231  -8.83387  19.46320  11.48775  5.45484 184.13026    .00979
       -.98705   -.01195   -.15995   -.15962   -.02523    .98686   -.01583    .99961    .02300
      29.98191  -8.83378  19.46358  11.48410  5.45568 184.13075    .00979
       -.98705   -.01195   -.15995   -.15961   -.02524    .98686   -.01583    .99961    .02300
      29.98207  -8.83394  19.46332  11.48550  5.45420 184.13048    .00979
       -.98705   -.01195   -.15995   -.15961   -.02524    .98686   -.01583    .99961    .02300
      29.98194  -8.83392  19.46347  11.48433  5.45441 184.13077    .00979
       -.98705   -.01195   -.15995   -.15961   -.02524    .98686   -.01583    .99961    .02300
      29.98200  -8.83394  19.46340  11.48492  5.45422 184.13078    .00979
       -.98705   -.01195   -.15995   -.15961   -.02524    .98686   -.01583    .99961    .02300
      29.98197  -8.83393  19.46343  11.48462  5.45431 184.13074    .00979
       -.98705   -.01195   -.15995   -.15961   -.02524    .98686   -.01583    .99961    .02300
      29.98199  -8.83392  19.46343  11.48482  5.45435 184.13080    .00979
       -.98705   -.01195   -.15995   -.15961   -.02524    .98686   -.01583    .99961    .02300
      29.98202  -8.83393  19.46336  11.48503  5.45432 184.13052    .00979
       -.98705   -.01195   -.15995   -.15961   -.02524    .98686   -.01583    .99961    .02300
      29.98198  -8.83391  19.46344  11.48470  5.45452 184.13078    .00979
      1 26.380438 -4.861560  .0008375
      2  4.185920 -4.937760  .0010381
      3  3.891280 17.302479  .0026324
      4 26.093418 17.818100  .0012070
      9 23.566120  5.803900  .0008343
     10 12.420600  5.910580  .0001535
     11  2.905760  5.991860  .0020173
     12 12.631420 -6.416040  .0005440
     13 12.237720 18.237200  .0005259
       -.98705   -.01195   -.15995   -.15961   -.02524    .98686   -.01583    .99961    .02300
      29.98200  -8.83391  19.46340  11.48492  5.45443 184.13060    .00979
1     set up parameters - lateral projection
        .04389   -.00293    .99903    .99892   -.01517   -.04393    .01528    .99988    .00227
       3.16778  -8.97930  15.70602  44.45662 16.28766 150.192081487.97229
       -.08163   -.04970    .99542    .99648   -.02306    .08056    .01895    .99850    .05141
       2.51471  -8.81139  13.89865  23.52338  8.10413 149.23682  45.38939
       -.17244   -.05655    .98340    .98496   -.02059    .17153    .01055    .99819    .05925
       1.10893  -8.95892  10.63221   9.24914  6.91589 139.99602    .19440
       -.15521   -.01355    .98779    .98780   -.01486    .15501    .01258    .99980    .01570
       1.51912  -8.40127  11.46772  12.50575 13.29204 140.83527    .17037
       -.17620   -.01257    .98427    .98429   -.01364    .17603    .01121    .99983    .01478
       1.27281  -8.39783  10.80466   9.45897 13.41144 138.94174    .04211
       -.17219   -.00647    .98504    .98500   -.01288    .17210    .01158    .99990    .00859
       1.32988  -8.31788  10.97785  10.08479 14.31426 139.26227    .03585
       -.17428   -.00675    .98467    .98463   -.01284    .17419    .01147    .99989    .00889
       1.30591  -8.32315  10.91266   9.78224 14.26912 139.08342    .03520
       -.17391   -.00628    .98474    .98469   -.01279    .17382    .01150    .99990    .00841
       1.31041  -8.31674  10.92883   9.83791 14.33949 139.11691    .03517
       -.17407   -.00631    .98471    .98467   -.01279    .17398    .01149    .99990    .00844
       1.30856  -8.31732  10.92386   9.81488 14.33423 139.10335    .03517
       -.17404   -.00628    .98472    .98467   -.01278    .17395    .01150    .99990    .00841
       1.30892  -8.31686  10.92514   9.81932 14.33915 139.10625    .03517
       -.17405   -.00628    .98472    .98467   -.01278    .17396    .01149    .99990    .00841
```

```
        1.30879  -8.31692  10.92477   9.81772  14.33866 139.10519    .03517
        -.17405   -.00628    .98472    .98467   -.01278    .17396    .01149    .99990    .00841
        1.30881  -8.31689  10.92485   9.81797  14.33892 139.10538    .03517
        -.17405   -.00628    .98472    .98467   -.01278    .17396    .01149    .99990    .00841
        1.30880  -8.31689  10.92483   9.81786  14.33896 139.10530    .03517
        -.17405   -.00628    .98472    .98467   -.01278    .17396    .01149    .99990    .00841
        1.30882  -8.31689  10.92485   9.81804  14.33901 139.10542    .03517
        -.17405   -.00628    .98472    .98467   -.01278    .17396    .01149    .99990    .00841
        1.30881  -8.31688  10.92487   9.81794  14.33908 139.10548    .03517
        -.17405   -.00628    .98472    .98467   -.01278    .17396    .01149    .99990    .00841
        1.30880  -8.31689  10.92482   9.81780  14.33897 139.10538    .03517
        -.17405   -.00628    .98472    .98467   -.01278    .17396    .01149    .99990    .00841
        1.30880  -8.31688  10.92483   9.81788  14.33910 139.10533    .03517
        -.17405   -.00628    .98472    .98467   -.01278    .17396    .01149    .99990    .00841
        1.30879  -8.31687  10.92483   9.81777  14.33912 139.10532    .03517
        -.17405   -.00628    .98472    .98467   -.01278    .17396    .01149    .99990    .00841
        1.30880  -8.31687  10.92483   9.81783  14.33912 139.10533    .03517
        -.17405   -.00628    .98472    .98467   -.01278    .17396    .01149    .99990    .00841
        1.30880  -8.31688  10.92485   9.81791  14.33909 139.10535    .03517
      5  7.426960 17.307560  .0081797
      6  6.134100 -4.932680  .0075463
      7 28.478479 -5.806440  .0020279
      8 28.740099 17.010380  .0026793
      9 28.242260  5.209540  .0089725
     10 14.858999  4.605020  .0010488
     11  -.726440  3.931920  .0001521
     12 14.732000 -8.168640  .0001277
     13 15.074900 17.482819  .0044327
       -.17405   -.00628    .98472    .98467   -.01278    .17396    .01149    .99990    .00841
       1.30881  -8.31688  10.92484   9.81791  14.33903 139.10544    .03517
1    back-check multiply acquired cal points


      9    5.0800   25.4000   15.2400    5.0860   25.3208   15.2453  .0063406
     10   15.2400   15.2400   15.2400   15.2532   15.2224   15.2299  .0005861
     11   25.4000    5.0800   15.2400   25.3830    5.0853   15.2235  .0005880
     12   15.2400   15.2400    5.0800   15.2349   15.2394    5.0657  .0002298
     13   15.2400   15.2400   25.4000   15.2366   15.2699   25.4122  .0010533
1    head anatomical to tee-plate transformation
     subject H00209  mount 1101  date APR88   notes HEAD DATA

0bee bee id i        measured x-ray coordinates        i       lab coordinates          i  sum of
the squares of the
            i                                          i                                i
difference between the
            i                                          i                                i
measured and best estimate
            i        ap                  lat           i                                i  of
x-ray coordinates
            i                                          i                                i
0           i    x         y         x         y       i    x         y         z       i    e
  1 r.audit    1.8085    7.7114    4.5161    5.9842       25.4972    9.0287   16.8190        .0031
  2 l.audit   16.1595    9.7104    7.7038    8.8671       12.9452    8.9599   18.3497        .0029
  3 r.orbit    2.5248   11.3309   17.8384    9.9949       22.8189   18.4356   19.8274        .0008
  4 l.orbit   11.6230   12.2276   18.8493   11.0896       15.3324   18.3475   20.4165        .0003
  5 c.t-plt    6.5151   14.3764   28.3108   12.8829       18.0769   25.8508   22.0095        .0007
  6 r.t-plt   -1.4757    6.6726   26.6421    4.5390       24.6725   25.0227   16.1485        .0015
  7 l.t-plt   14.4704    6.0681   26.7767    4.9403       12.2026   24.4568   15.5134        .0011
0              right/left switch follow below
0 8 r.audit    1.8085    7.7114    7.7038    8.8671       24.9421   11.2660   18.0525       3.7105
  9 l.audit   16.1595    9.7104    4.5161    5.9842       13.3660    6.4079   17.0826       3.8006
 10 r.orbit    2.5248   11.3309   18.8493   11.0896       22.6515   19.1498   20.2684        .6052
 11 l.orbit   11.6230   12.2276   17.8384    9.9949       15.4720   17.5776   19.9732        .5842
 12 r.t-plt   -1.4757    6.6726   26.7767    4.9403       24.6381   25.1154   16.3048        .0536
 13 l.t-plt   14.4704    6.0681   26.6421    4.5390       12.2300   24.3515   15.3570        .1033
  option  1 vs  8 not indicated
  option  3 vs 10 not indicated
  option  6 vs 12 not indicated
1plexiglass t-plate coordinate system-orientation and location of bee bees
```




| | | x | y | z |
|---|---|---|---|---|
| location of bee bees in instrumentation: | bb 1 | .0000 | .0000 | .0000 |
| | bb 2 | 6.2860 | -6.2860 | .0000 |
| | bb 3 | 6.2860 | 6.2860 | .0000 |

1 head anatomical to tee-plate transformation
subject H00209 mount 1101 date APR88
notes HEAD DATA

anatomy vs lab

| | | | |
|---|---|---|---|
| 19.2212 | -.01495874 | .96531314 | .26066601 |
| 8.9943 | -.99450266 | -.04138450 | .09618630 |
| 17.5844 | .10363743 | -.25779423 | .96062553 |

instrumentation vs lab

| | | | |
|---|---|---|---|
| 18.0748 | .05787801 | -.99769205 | -.03550632 |
| 25.8505 | -.17667633 | -.04524093 | .98322874 |
| 22.0081 | -.98256588 | -.05063419 | -.17888699 |

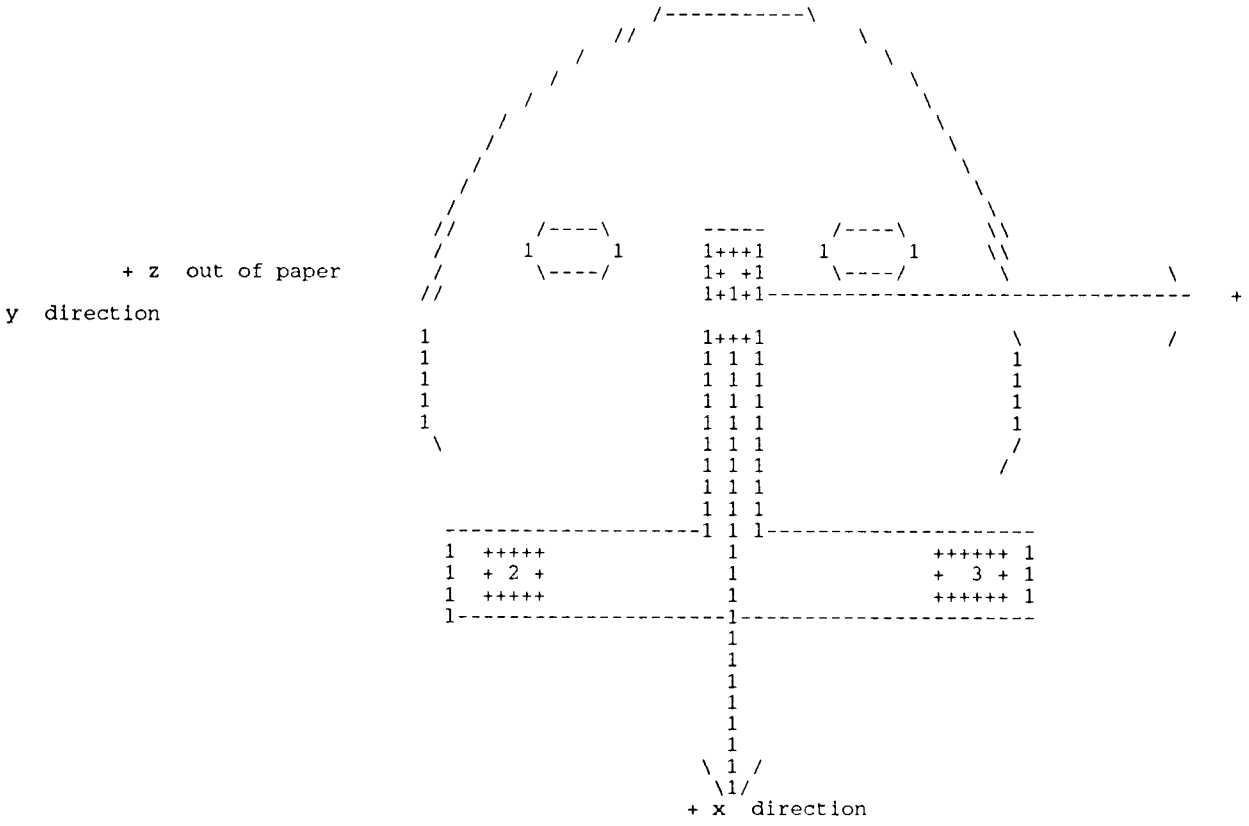
instrumentation vs anatomy

| | | | |
|---|---|---|---|
| 17.4417 | -.42753530 | -.04194606 | .90302497 |
| .8681 | -.14475755 | .98920941 | -.02258578 |
| -.2147 | -.89233339 | -.14037588 | -.42899388 |

1 t-1 anatomical to tee-plate transformation
subject H00209 mount 2201 date APR88
notes NECK DATA

| 0bee bee id i | measured x-ray coordinates i | lab coordinates i | sum of the squares of the i |
|---|---|---|---|

```
difference between the
          i                                        i                                  i
measured and best estimate
          i       ap                  lat          i                                  i  of
x-ray coordinates
          i                                        i                                  i
0         i    x         y         x         y     i    x         y         z         i    e
0 1 p-spine   12.0117    4.0564    16.0223    2.6543     15.4639   16.1980   13.7306        .0004
  2 s-notch   10.7086   -4.0843    30.2260   -5.0521     14.7823   27.3728    7.9246        .0003
  3 c.t-plt   12.8016   11.2928     -.9398   10.7620     16.7990    2.6589   19.8672        .0202
  4 r.t-plt    5.0597   11.4859     5.9131   10.1854     22.5042    9.4179   19.8886        .0269
  5 l.t-plt   19.5529   10.6045     7.7546    9.6622     10.0794    8.4461   18.9701        .0112
0              right/left switch follow below
0 6 r.t-plt    5.0597   11.4859     7.7546    9.6622     22.2442   10.7782   19.6704        .2348
  7 l.t-plt   19.5529   10.6045     5.9131   10.1854     10.2519    6.8995   19.1873        .0556
  option  4 vs  6 not indicated
1plexiglass t-plate coordinate system-orientation and   location of bee bees
```




```
                                                    x         y         z
                                          bb 1      .0000     .0000     .0000
     location of bee bees in instrumentation:  bb 2     6.2860   -6.2860     .0000
                                          bb 3      6.2860    6.2860     .0000
0    articular facets      5.8522    4.0005   17.5768    3.7059
0    lateral projection   25.9664    -.1499   17.4422    1.5608
           14.9090         24.0173         11.6953
           15.4044         17.3306         12.8952
1     t-1 anatomical to tee-plate transformation
     subject H00209  mount 2201  date APR88
           notes  NECK DATA
```

anatomy vs lab

```
 14.9090   -.07271960 .98167169-.17616072
 24.0173   -.99600524-.08065766-.03831476
 11.6953   -.05182123 .17267077 .98361552
```

instrumentation vs lab

```
 16.7738   -.07466944-.99411541-.07847808
  2.6720    .99481934-.07970386 .06310345
 19.8644   -.06898712-.07335965 .99491668
```

instrumentation vs anatomy

```
-22.5287    .99416876 .00697174-.10761147
  -.4487   -.00322542 .99938363 .03495481
  4.2529    .10778888-.03440393 .99357843
```

# APPENDIX E

## Listing of "UPDATE"

```
H00209  1101  APR88              HEAD DATA                    0   0   0   0
 17.441742     .868058    -.214688
-.42753530  -.14475755  -.89233339
-.04194606   .98920941  -.14037588
 .90302497  -.02258578  -.42899388
H00209  2201  APR88    BLOCK     NECK DATA                    0   0   0   0
-22.528715    -.448652    4.252915
 .99416876  -.00322542   .10778888
 .00697174   .99938363  -.03440393
-.10761147   .03495481   .99357843
```